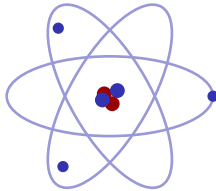


Particle Physics

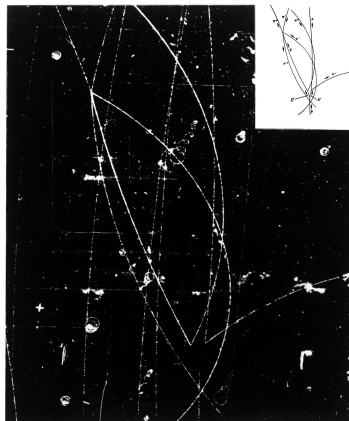
AS Physics ■ Topic 11

A-Level Physics



What we will cover

- 1 α -scattering & the nucleus
- 2 Nuclide notation & isotopes
- 3 Radioactive emissions
- 4 Decay equations
- 5 Quarks & fundamental particles
- 6 Recap

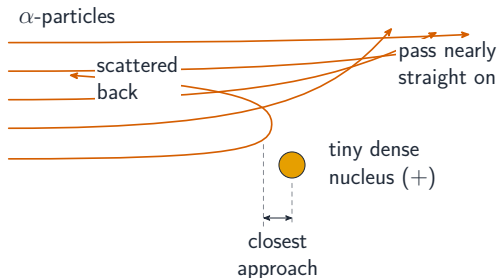


Production and decay of neutral lambda and anti-lambda hyperons

1

The nuclear atom

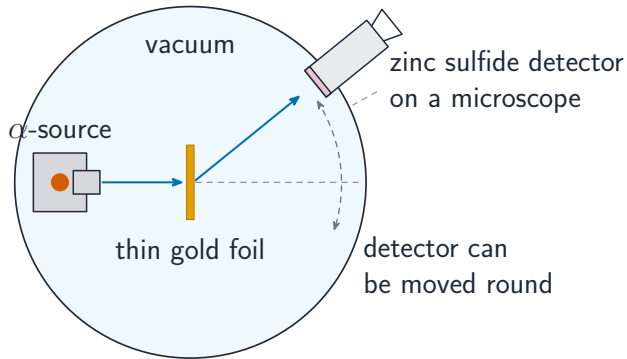
α -particle scattering



- mostly pass straight through, with very little **deflection** 偏转,
- sometimes deflect through small angles,
- rarely (about 1 in 8000) deflect through angles greater than 90° .
- so: a **tiny, dense, positively charged nucleus** 原子核 at the centre
- the atom is **mostly empty space** (most α -particles pass straight through),

The experiment itself

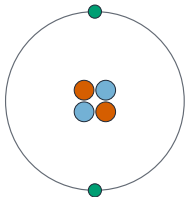
Almost every α went straight through; a very few came **straight back**. That is only possible if the positive charge sits in a tiny, massive core.



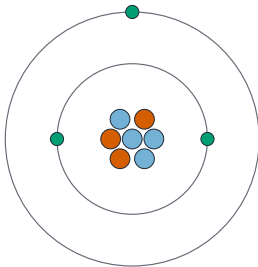
The nuclear model

The rare large deflections need a **tiny, dense, positively charged nucleus** at the centre to push the α away.

a) helium



b) lithium



- proton (charge $+e$) ● neutron (no charge)
● electron (charge $-e$)

- **protons** 质子 ($+e$) and **neutrons** 中子 (0) in the nucleus, ≈ 1 u each
- **electrons** 电子 ($-e$) around it, $\frac{1}{1836}$ of the mass

Unified atomic mass unit

The **unified atomic mass unit** 统一原子质量单位, symbol u, is set so that one atom of $^{12}_6\text{C}$ has a mass of exactly 12 u.

$$1 \text{ u} = 1.661 \times 10^{-27} \text{ kg}$$

proton

$$\approx 1.007 \text{ u}$$

neutron

$$\approx 1.009 \text{ u}$$

electron

$$\approx 5.5 \times 10^{-4} \text{ u}$$

A **nucleon** 核子 is about 1 u, so the nucleon number A is very nearly the mass in u.

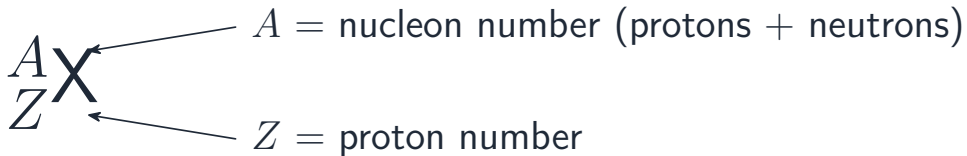
Nuclide notation and isotopes

A nucleon number
 Z proton number
 X

- neutrons $N = A - Z$
- **isotopes** 同位素: same Z , different numbers of **neutrons** 中子 and so different A (e.g. ${}^1_6\text{C}$, ${}^{14}_6\text{C}$) – chemically alike, nuclearly different

In every nuclear process the **nu-
cleon** 核子 number A and the **charge** are conserved. Balance both to write any decay equation.

Reading the notation



Top is the **nucleon number** 核子数 A , bottom the **proton number** 质子数 Z .
Isotopes 同位素 share Z and differ in A .

2

Radioactive emissions

Three kinds of radiation

 α

He nucleus
+2e, ≈ 4 u
stopped by paper
discrete energy

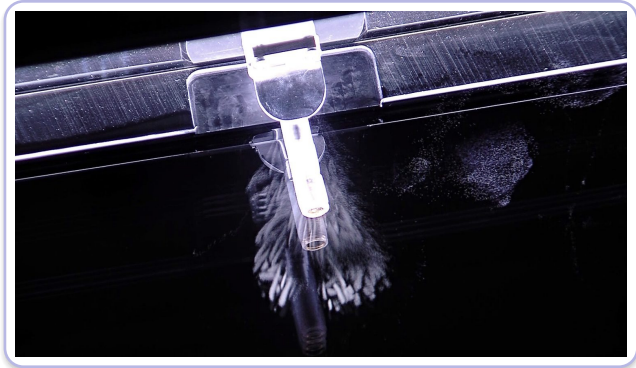
 β

fast electron/positron
 $\pm e$, tiny mass
stopped by Al
continuous energy

 γ

photon 光子
0 charge, 0 mass
attenuated by lead
discrete energy

Tracks in a cloud chamber

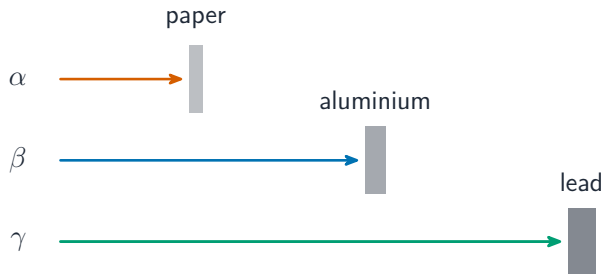


α tracks are short, straight and thick – heavily ionising, quickly stopped.

Penetrating power

- α – paper
- β – a few mm of aluminium
- γ – only attenuated by lead

Ionising power is the reverse order: α strongest.



A γ -ray is a photon, not a particle

- made of a high-energy **photon** 光子 – part of the **electromagnetic spectrum** 电磁波谱
- **zero** rest mass, **zero** charge
- long range in air; **attenuated** 衰减 rather than stopped – several cm of lead, or a metre of concrete
- weakest **ionising** 电离 power of the three
- a **discrete** energy spectrum: the nucleus drops between two nuclear energy levels

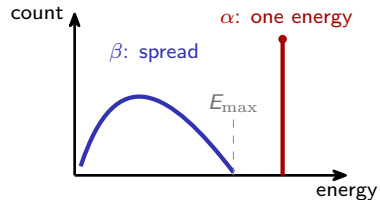
It is usually a **tidy-up** step: an α or β decay leaves the **daughter nucleus** 子核 in an **excited state** 激发态, and the γ carries off the surplus.

That is why γ alone never changes A or Z .

Antiparticles and the neutrino

Every particle has an **antiparticle** 反粒子: same mass, opposite charge (positron = anti-electron). β -decay always emits a third particle:

- β^- : an **antineutrino** 反中微子 $\bar{\nu}_e$
- β^+ : a **neutrino** 中微子 ν_e



α : energy shared by 2 bodies
→ discrete. β : shared by 3 →
continuous – the neutrino takes
a varying share.

Why the neutrino had to exist

The problem

In β -decay the emitted electron comes out with a *range* of energies, not the single value a two-body decay demands.

The fix

A third particle carries off the rest. Neutrinos and antineutrinos have zero charge, very small mass, and barely interact.

What it saves

They are hard to detect, but they must be there to balance energy, **momentum** 动量 and the other conserved quantities.

Counting nucleons

The **nucleon number** 核子数 A is the total number of **nucleons** 核子 – protons plus neutrons – and it balances on both sides of every decay equation.

A conservation law that appears to fail is a prediction: something unseen is carrying the difference.

Writing decay equations

$${}^A_Z\text{X} \rightarrow {}^{A-4}_{Z-2}\text{Y} + {}^4_2\alpha$$

$${}^A_Z\text{X} \rightarrow {}^A_{Z+1}\text{Y} + {}^0_{-1}\beta + \bar{\nu}_e$$

Balance A (top) and Z (bottom) on both sides:

nucleon 核子 number is conserved, and so is charge – **conservation of charge** 电荷守恒.

U-238 (α) and C-14 (β^-)

$${}^{238}_{92}\text{U} \rightarrow {}^{234}_{90}\text{Th} + {}^4_2\alpha$$

$${}^{14}_6\text{C} \rightarrow {}^{14}_7\text{N} + {}^0_{-1}\beta + \bar{\nu}_e$$

check: $A\ 238 = 234 + 4$ ✓ $Z\ 92 = 90 + 2$ ✓

3

Fundamental particles

Quarks

Six **quark** 夸克 flavours:

- u, c, t carry $+\frac{2}{3}e$
- d, s, b carry $-\frac{1}{3}e$

Each **antiquark** 反夸克 has the opposite charge.

Quarks, in detail

charge $+\frac{2}{3}e$

up
u

charm
c

top
t

charge $-\frac{1}{3}e$

down
d

strange
s

bottom
b

each antiquark has
the opposite charge

Only **u** and **d** build ordinary matter – a proton is uud, a neutron udd. The other four appear only at high energy.

Hadrons: baryons and mesons

Particles built from quarks are **hadrons** 强子:

baryons 重子

three quarks
proton (u u d), neutron (u d d)

mesons 介子

one quark + one antiquark
e.g. $\pi^+ = u\bar{d}$

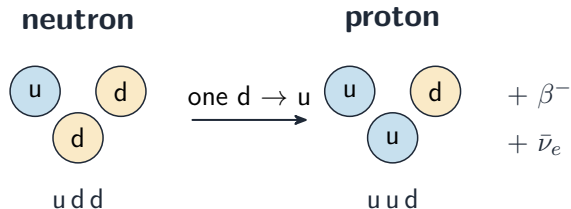
Protons and neutrons are **not** fundamental – they are baryons.

β -decay at the quark level

A neutron $\rightarrow$ proton: one **down** quark becomes an **up** quark.

$$d \rightarrow u + \beta^- + \bar{\nu}_e$$

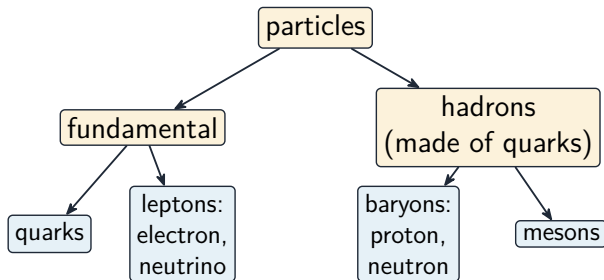
$$(\beta^+: u \rightarrow d + \beta^+ + \nu_e.)$$



Beta-minus decay: one down quark becomes an up quark, turning a neutron into a proton

Some particles are **fundamental** 基本粒子 (point-like, with no smaller parts as far as we know); others are built from fundamental ones.

Classifying particles



Fundamental: **quarks** 夸克 and **leptons** 轻子 (electron, neutrino).

Built from quarks: protons, neutrons, baryons, mesons.

Exam tips

- Describe the **nuclear atom** (a small, dense, positive nucleus) using the alpha-scattering evidence.
- Compare α , β and γ by **charge, mass, ionising power and penetration**.
- Use quark composition (proton uud , neutron udd) and check that **charge and nucleon number balance** in an equation.
- In β^- decay a neutron becomes a proton, an electron and an antineutrino.

4

Recap

Topic 11 – key takeaways

1

Nuclear atom

tiny dense + nucleus; ${}^A_Z\text{X}$, A & charge conserved

2

Radiation

α (paper), β (Al), γ (lead)

3

β & neutrinos

3 bodies $\rightarrow$ continuous spectrum

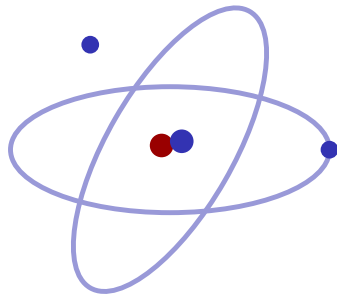
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Quarks

hadrons from quarks; quarks & leptons fundamental

Check yourself

- 1 What did the rare large α deflections show?
- 2 $^{226}_{88}\text{Ra}$ decays by α – the daughter's A and Z ?
- 3 Which radiation is a photon?
- 4 Quark content of a neutron?



Answers 1. a tiny dense nucleus 2. $A = 222$, $Z = 86$ 3. γ 4. u d d